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MATERIALS PROCESSING IN LOW GRAVITY

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1.0 Introduction

This report covers the continuation of the Materials Processing in Low Gravity Program in which The University of Alabama in Huntsville designed, fabricated and performed various low gravity experiments in materials processing from October 26, 1988 through October 25, 1989. The facilities used in these short duration low gravity experiments include the Drop Tube and Drop Tower at MSFC, and the KC-135 aircraft at Ellington Field.

During the performance of this contract, the utilization of these ground-based low gravity facilites for materials processing experiments has been instrumental in providing the opportunity to determine the feasibilty of performing a number of experiments in the microgravity of Space, without the expense of a space-based experiment.

Since the KC-135 was out for repairs during the latter part of the reporting period, a number of the KC-135 activities concentrated on repair and maintenance of the equipment that normally is flown on the aircraft.

A number of periodic reports have been given to the TCOR during the course of this contract, hence this final report is meant only to summarize the many activities performed and not redundantly cover materials already submitted.

2.0 Tasks Accomplished

2.1. In collaboration with scientists from MSFC and industry, UAH has defined, developed, and conducted materials processing experiments in low gravity using the Drop Facilities at MSFC and the KC-135 aircraft at Ellington Field. This effort has included the defining of experimental requirements and equipment, experiment-facility integration requirements, building/assembling the necessary experiment apparatus, and conducting experiments which will contribute to the knowledge base for commercialization of materials processing in low gravity. UAH has also performed the logistical support needed to execute the experimentation, and the necessary sample preparation, metallography analysis/interpretation and physical properties measurements of processed samples. UAH has interfaced with designated MSFC scientists and project representatives who will provide Center policy, programmatic requirements and goals, priorities, and scientific and technical advice.

2.1.1. All ground based facilities have been very productive during the duration of this contract. The Drop Facilities at MSFC are worked daily to perform drop experiments, build up experimental hardware for drops, and provide maintenance on existing instrumentation. Dr. Mike Robinson has provided the leadership for MSFC in over-seeing this facility and its function within NASA's materials processing program. Tom Rathz is in charge of the UAH activities at the Drop Facilites and works quite closely with Dr. Robinson in determining and meeting scientific objectives at the Drop Facilities.

Current experimental hardware which is being used still includes the following:

DROP TUBE: Electromagnetic Levitation Furnace.
Electron Beam Furnace.

DROP Tower: Critical Point Wetting Experiment
High Temperature Vacuum Furnace

2.1.2 UAH supported the KC-135 for seven missions during the contract period. Scheduling of the aircraft is performed by Dr. Robert Shurney of MSFC with the UAH personnel adhering to that predetermined schedule. Slippages due to aircraft down-times are the major reasons for any cancellations in scheduled aircraft experiments, and during this contract the crack in the landing gear of the KC-135 was the limitation in performing KC-135 experiments.

The primary experimental hardware which is being used for KC-135 experiments still includes the Advanced Directional Solidi-fication Furnace (ADSF) and the Isothermal Casting Furnace (ICF). In addition UAH has assisted in the transport of an Orbital Tube Welder Experiment provided by Richard Poorman of MSFC and used by Rocketdyne personnel in their Welding in Space experiment. Also a Laser Welding experiment for UAH has been transported to JSC on a number of occasions. These projects were able to partially assist in covering some of the travel costs for transporting the items to JSC.

In addition we have assisted in transporting and flying two new furnaces for SSL, the Rapid Melt/Rapid Quench solidification experiment and the Polymer Video Furnace to fly on the KC-135. Additional funds were also available to help offset the higher travel costs associated with these experiments.

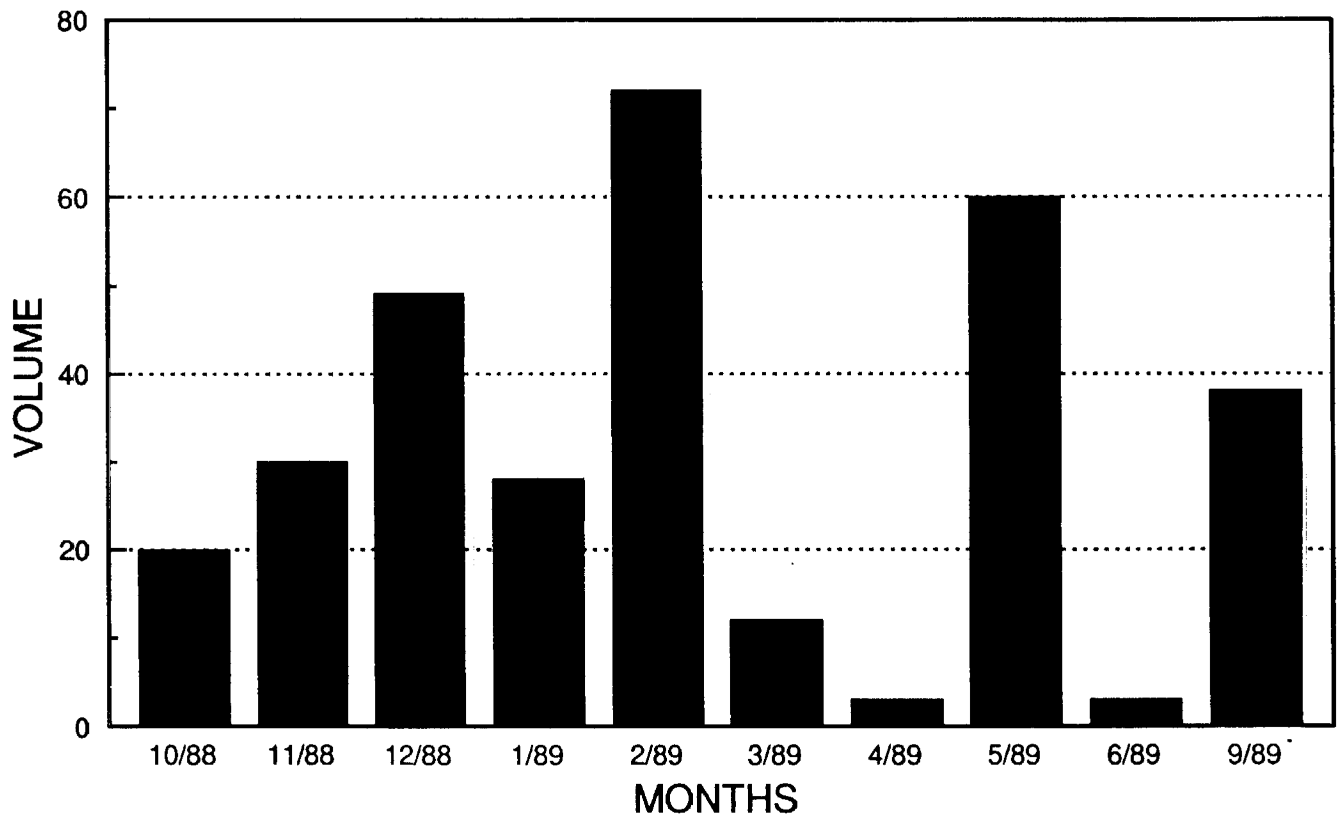
2.1.3. UAH is fortunate to continue with experienced personnel and no long down times has continued to maintain a productive facility. As an example of the continued progress made in productivity of the Drop Tube, the chart below lists the number of drop tube experiments made at the facility during FY88 and FY89.

DROP TUBE PRODUCTIVITY

	MONTH	DROPS	MONTH	DROPS
	10/87	48	10/88	20
	11/87	55	11/88	30
			12/88	49
	1/88	24	1/89	28
	2/88	40	2/89	72
			3/89	12
			4/89	3
	5/88	85	5/89	60
	6/88	63	6/89	3
	8/88	64		
	9/88	25	9/89	38
TOTALS		404		315

Figure 1 shows a histogram of the drop distribution. The reason

FIGURE 1. DROP TUBE DROPS

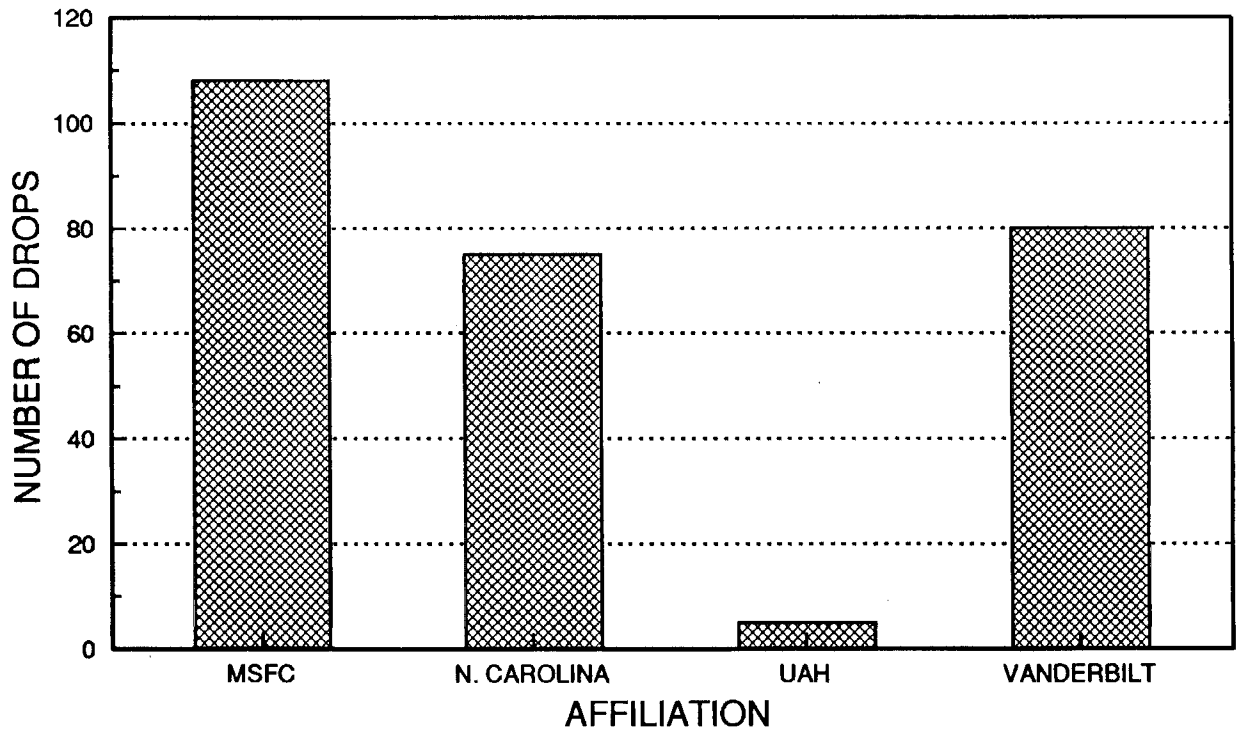


for the smaller number of drops in FY89 is due to a decrease in the number requested by the Vanderbilt University group. A major factor in the small number of drops during the summer months was also due to sand-blasting operations on the building being performed by a NASA contractor. Many delays were encountered in being able to make drops during that time period. The months in which no data are shown were months when either equipment break-down or testing occurred or on occasion, testing and installation of new equipment on the facility was necessary or due to sand-blasting.

The total number of drops is also affected by the number of users who want to use the facility. As an example, during the time period above, the users were Vanderbilt, University of Alabama in Birmingham, North Carolina State University, and MSFC. Vanderbilt is the major user of the facility. Their experiments have been both scientific and commercial. Figure 2 shows a histogram of the distribution over the research groups. In addition several students have received their Ph.D. degrees from Vanderbilt and North Carolina State using data from the Drop Tube experiments. As is obvious from the charts, there is substantial amount of interaction between Vanderbilt and MSFC in determining scientific needs and requirements of the Drop Tube. All current commercial customers use the facility through the Vanderbilt Consortium.

2.1.5 The Drop Tower has also continued in becoming more

FIGURE 2. DROP PRODUCTION PER AFFILIATION



productive during this contractual period. Mr. Jeff Sinex is in charge of the facility and although he is still new to this type of operation, he has performed well.

Over the last several years, several major repairs to the tracks have been performed to eliminate any accelerations during the drop and the nose section of the drag shield has been reinforced. Some attempts were made to modify the catch tube's air flow pattern to ameliorate the maximum G's at the end of the drop; however, either the drag shield hit with a thump or it bounced several times. Either occurrence was undesirable, therefore we ended up with partial air flow to be in the middle. As addressed later on, we have also made progress in improving the data acquisition for Drop Tower experiments.

As listed above the two experimental packages used during this period at the Drop Tower are the Critical Point Wetting (CPW) and the High Temperature Vacuum Furnace (HTVF). Dr. William Kaukler is the principal investigator for the CPW and Dr. M. K. Wu and Dr. Mohri are the P.I.'s for some solidification experiments for the HTVF. During this period the Drop Tower production rate was up to around 22 official drops, not including several test drops for checking out particular components of an experiment package or the drag shield itself.

Neither Dr. Kaulkler or Dr. Mohri are currently considered Drop Tower users. Dr. Kaukler's project on critical wetting was successfully completed and Dr. Mohri returned to Japan. We have suggested to Dr. Mohri that he make an official request through international channels to resume the work. No word on that matter has been received as yet. During the time period that Dr. Mohri was using the Drop Tower, a considerable amount of effort was given by Dr. Kaukler in assisting with the Drop Tower drops and with the analysis of the data.

2.1.6. The KC-135 activities have also been quite active during this contract period. For this task we have been primarily concerned with experiments that have been performed with the ADSF and the ICF furnaces. Scientific investigators for these furnaces include many collaborations that Dr. Pete Curreri has established with the University of Alabama in Tuscaloosa, Rockwell International, and UAH. In collaboration with Mr. Jimmy Lee at MSFC/M&P Laboratory we have processed a number of superalloy samples in conjunction with his collaborators from Pratt & Whitney and Cleveland State University.

The Vanderbilt Consortium has flown only one mission on the KC-135 during this period. Dr. Donald E. Morel for Applied Research Laboratory was the principal investigator for studying metal matrix composites. The Clarkson University consortium has also flown using the polymer video furnace. Guy Smith worked with both groups in performing ground-based studies to prepare for the parameters needed in flight.

The lack of a large number of experiments suggests that results from these types of experiments may not be as easily understood in terms of what goals are set for KC-135 experiments.

For instance if an experimenter anticipated the type of data obtained is a space-based experiment or if he under-estimates the work required to interpret the directional solidification results properly, then the utility of the KC-135 as an experimental platform may be received negatively. Perhaps this indicates that the program should provide a better understanding of what experimental results can be achieved in the KC-135 environment. To help meet that end, Dr. Kaukler and I have submitted a request to develop a video convective flow analyzer to determine what fluid flows mechanisms do exist as the KC-135 flies parabolic manuevers. In anticipation that it is funded, the information will be valuable to many KC-135 experimentalists.

2.2. UAH has developed procedures delineating the objectives, test sequence, operational timeline, etc., prior to each experiment or experiment series. This includes performing ground-based checkouts of experiment apparatus and support systems, both for pre-experi-ment/flight and ground control. UAH has also installed and tested suitable apparatus in the facilities in order to provide the appropriate processing conditions required for the experimental work, recorded and analyzed experiment apparatus operation parameters and thermal profiles as appropriate to interpret results of the experiments.

For this work UAH used existing equipment such as the E-beam furnace and the electromagnetic levitation furnace at the Drop Tube.

2.2.1. UAH personnel have continued work on performing tests and check-outs on all facilities as part of the facilities requirements. The Drop Facilities need extensive mechanical and electrical preventative maintenance, which UAH is not authorized to perform. SSL does provide technician support for this activity. This arrangement works well, since the technician can interface more easily with MSFC facilities and supply personnel.

2.3. Where required UAH has formulated written scientific and/or engineering reports for each experiment and/or experiment series. These reports were augmented with metallurgical reports where appropriate and were provided on a timely basis for internal program use. No reports or publications intended for distributions to other organizations or individuals included data furnished to NASA with restrictive legends by third parties.

2.3.1. After the experiments are performed, each scientific investigator for each facility or experiment receives their samples, the data derived from each experiment, and any additional comments which might assist in the interpretation of the experiment. For the Drop Tube this data set include pyrometric data, pressure measurements, and electrical parameters effecting the molten droplet. For the Drop Tower this data includes acceleration profiles, temperatures, and other pertinent parameters. For the KC-135 experiments the data includes strip charts and computer data files with temperature, acceleration, and position of sample.

2.4. UAH has provided consultation, expert interpretation of experiment results of metallurgical and chemical processes, expert analysis and interpretation of optical records taken during low gravity experiments, and recommendations for research tasks being conducted under this contract.

2.4.1. This activity has in general been performed upon request from other groups using or wishing to use the ground-based facilities. Both Guy Smith for the KC-135 operations and Tom Rathz for the Drop Facilities have responded to numerous requests about particular features of performing experiments in those facilities. Dr William Kaukler has also assisted in responding to outside requests for information about use of the facilities or general information about experimentation in low gravity. In addition, we have received many visiting groups at the Drop Facilities which have been escorted through by Public Affairs Office at MSFC. Guy Smith has provided some expert advise in the fabrication of furnace cores to a number of groups who are building furnaces. This includes groups like Wyle Labs in building their Video Furnace and the Rapid Melt/Rapid Quench Furnace. His expertise has developed over the years and it continues to be beneficial to the NASA MPLG program in a number of different ways. He has also been able to train student workers in the art of winding the furnace cores such that we are able to provide assistance when needed.

2.4.2. In general other than tour groups visiting the Drop Facilities, we have not been requested by too many outside groups to provide expertise on low gravity materials processing. Due to the nature and the diversity of the many experiments we perform at the various facilities, we feel that we should be more beneficial to the program than we currently are. An accumulation of knowledge from building many experimental packages at the various facilities is certainly useful in designing a scientific experiment for space, that would benefit from preliminary experiments at any of the ground-based facilities. It would appear from our perspective that the many programs initiated by NASA for new hardware do not seem to follow a master plan. If such a plan existed it would certainly make it easier for groups such as ours to make inputs into the role that the ground-based facilities can play in the various materials processing programs.

2.4.3 Task 2.5, as stated below actually prohibits us from making presentations at technical conferences concerning any scientific work being performed at the facilities, without the scientific investigator being involved. In order not to show any indication of bias by being part of some experiments that we run at the facilities, we have not made a substantial effort to become part of a particular research team. Therefore we are basically open with everyone.

However; as part of a university research organization, we are often requested to attain more refereed publications. Consequently we are frequently encouraged to find ways to publish without violating the philosophy of Task 2.5. We are currently working on ideas to fulfil these needs. They would certainly be beneficial to the overall objectives of the program. Collectively, a number of papers were presented at the Alabama Materials Research Conference in the Fall. All topics covered use of the facilities for low gravity experiments and not on reporting of any experimenter's results.

2.5. UAH has maintained procedures to protect proprietary and trade secret data provided by an industrial organization from unauthorized disclosure.

2.5.1. UAH has performed this task accordingly by not publishing or sending anyone's data to anyone other than the scientific investigator himself. The TCOR, in this case Dr. Robinson, is always consulted before sending out any information which is not already in the public domain. We have made general presentations about Materials Processing in Low Gravity, but only used information currently open to the public or already published. Dr. Pete Curreri for KC-135 experiments and Dr. Mike Robinson for the Drop Facilites serve as the officials who determine what information can be transmitted.

A concern of mine, of which the philosophy of this task basically helps to propagate, is that officially we are authorized only to transmit the data and the samples to the scientific investigators. We have no mechanism for the investigators to share with us the results of the experiments. Unfortunately this information would be useful for the purpose of maintaining optimal control of the experimental parameters and hardware. Since we do not in general get feedback from the scientific investigators about their scientific results, we are quite limited in determining if our experiments are really what the investigator wanted. Thus this feedback could be used to determine any future modifications or experimental changes required to optimize upon particular experiments.

2.6. UAH has conducted various experimental drops, as directed, associated with operational readiness demonstrations of the drop tube facility and scientific investigations.

2.7. Since the recording of droplet temperatures as a function of drop time in the Drop Tube is such an important part of most Drop Tube experiments, it is necessary to continue to search for and evaluate for the most cost effective method for determining transit droplet temperature along the length of the Drop Tube in order to make recommendations for implementation of such a method or methods. Upon specific direction procure, install and verify equipment and/or instrument required to implement the preferred method.

2.7.1. This problem has a long standing thrust in materials processing experiments in low gravity. Non-contact temperature measurement is required to understand solidification phenomena, fluid behavior, etc in containerless environments. The most progress has occurred since Tom Rathz has taken charge of the facility and Boyd Shelton was hired to respond to electronic instrumentation requirements at the Drop Facilities.

2.7.2. Over the years additional work and analysis have been performed by members of our group, Tom Rathz and Dr. William Kaukler and by others such as Dr. William Hofmeister of Vanderbilt University. Alternatives included high gain Si detectors, temperature stabilized Si detector, and logarithmic amplifiers. Dr. Robinson has basicly decided that logarithm amplication using silicon detectors was the optimal choice. Hence Boyd Shelton has continued to work with that system, performing experiments in parallel with other activities at the Drop Facilities. We currently believe that this method will perform adequately for the tasks at hand when fully optimized. Tom Rathz has also implemented quartz light-pipes at the Drop Tube to increase the quantity of radiance from recalescence collected by the detectors. We see noticeable improvements in the S/N level of these signals.

2.7.3 Tom Rathz has been able to participate to some extent with the Non-contact Temperature Measurement Working Group. Thus he is able to at least keep abreast of other techniques which are being considered in NASA's various programs.

2.8. Upgrade Drop Tube and Drop Tower experiment apparatus capability through continual evaluation of experiment and operational requirements.

2.8.1. In addition to the detectors required for temperature measurement of falling drops, UAH personnel have made a number of improvements to increase the productivity of the Tube and improve upon the data collection process for the facilities. Continual up-grading of the Soltec High Speed Data Acquisition system, which is interfaced to both the optical pyrometer and the silicon detectors has been maintained. In addition the video capability can also be used for observing samples during the sample heating and melting periods in the belljar is still working quite well. We are also still using an optical disk for archiving drop facilities data. A number of modifications have been made to improve upon the ease of sample changing in both the belljar and the catch tube. These modifications have been instrumental in improving control of samples during processing and quicker turn-around time in running experiments.

2.8.2 The infra-red laser transmitter-receiver has been installed at the Drop Tower for real-time data acquisition purposes. The band-width of the system also allows video transmission. After a lot of problems in the original equipment as received, we have succeeded in making the system functional. After some more experimentation and a better understanding of the geometries involved in the Drop Tower facility, we should be optimized in the near future.

2.8.3 A Drop Tube User's Manual has been prepared by Tom Rathz and distributed. A Drop Tower User's Manual has been prepared by Jeff Synex and will probably be available during the next contract period.

2.9. Upgrade, as required, the drop tube and drop tower experiment packages associated with MSFC approved experiments and conduct drops necessary to support the investigation. Continuous improvement in the operational characteristics of both facilities has occurred. For instance the Drop Tube has improved the vacuum attainable by increasing the number of pumps, improvement in temperature measurements with both a new optical pyrometer and new detectors, and evolving redesigns in sample holders and retrieval systems. Also notable in terms of determining recalescence in undercooled samples is the addition of a video camera looking up the tube from the bottom. If recalescence does occur, it is captured on the video tape for comparison with the data from the Si detectors. Some discussion has occurred with respect to using this data for temperature determinations during the drop; however, the complexity of the task makes it less desirable than using the Si detectors at this time. With improvements in CCD's and imaging systems in the future, we may reconsider this capability again.

2.9.1 Notable improvements during this contract period include upgrading the Drop Tube data acquisition from a 80286 to a 80386 CPU, implementation of an Axiom TX-2000 video printer for the tube data plots, and an E-beam camera mount for improved visualization of E-beam melts. Improvements in operation also include the use of 0.125" alumina felt in the catch tank to prevent fragmentaion of fragile drops.

2.10. Modify existing packages for use on the KC-135 aircraft and develop new packages as necessary, prepare material samples, conduct ground tests using the experimental packages, and operate experiments on the aircraft. Analyze results and prepare samples.

2.11. Conduct special studies to define new experiments to be perfomed on the KC-135 aircraft and establish the requirements for the equipment to be used to carry out the experiments.

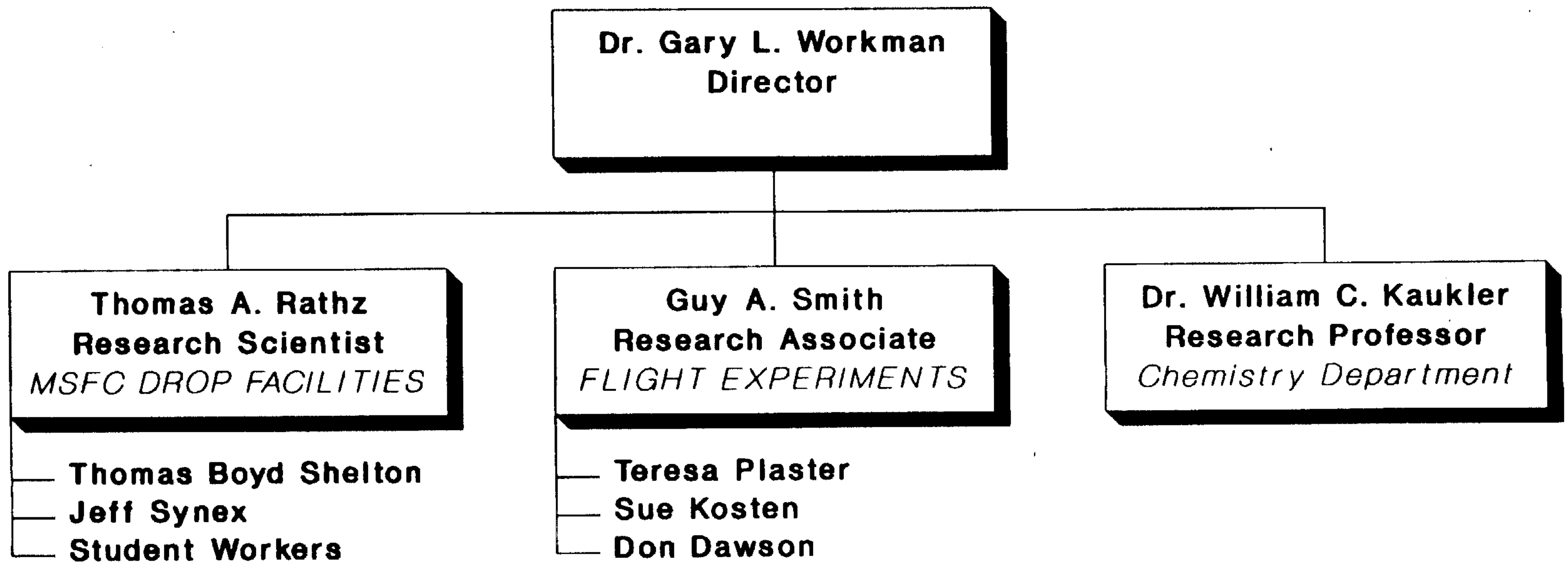
2.11.1. Guy Smith and his staff have also continued to work on the construction of a three-zone ADSF for the KC-135 experiments in parallel with all the other activities being performed for KC-135 experiments. It also will probably be ready for flight during the next contract period. The major problem facing KC-135 furnace activity is that we certainly will not be able to fly all of them at the same time. After the Video Furnace and the Rapid Melt/Rapid Quench are made flight ready and the three-zone ADSF is operational, there will have to be some scheduling worked out to optimize the use of all the furnace capability for the aircraft. Due to power limitations and the problem of long soak times affecting the number of parabolas obtained during a mission, only one or two furnaces can really ever fly at the same time. In addition, there is the continuing problem of the new hardware being transported to Ellington getting larger and heavier; thereby making transportation more difficult. With sufficient planning there would be more optimal control for implementation of all the furnaces.

2.11.2 Additional activities which have supported other experiments flying on the KC-135 include assistance with the Polymer Video Furnace and Rapid/Melt Rapid Quench Furnaces and making temperature measurements for the Orbital Tube Welder of Richard Poorman/MSFC. All of these activities were partially supported to cover additonal hardware and travel expenses caused by their implementation.

3.0 Personnel

The following chart, Figure 3, shows the organization chart for the Materials Processing Laboratory in the Johnson Research Center. This Laboratory has basically evolved during this

JOHNSON RESEARCH CENTER
MATERIALS PROCESSING LABORATORY



contract period to meet the needs of this program and to better respond to future needs of microgravity materials processing programs.

4.0 Acknowledgements

The work performed on this contract was successful due to the fact that many people were able to provide help and assistance in meeting the above goals. This includes Dr. Robert Shurney, NASA/MSFC and Mr. Robert Williams, NASA/JSC in the KC-135 program, Dr. Mike Robinson and Kevin Vellacott-Ford at the Drop Facilities, and of course, the many UAH personnel who have worked with each of the facilities reported here.